

The Development of Planar Fiber-Optic Microprobes for Rapid, Remote Assessment of Seafloor Bulk Properties and Sediment Grain Size

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LONG-TERM GOALS

The operational Navy seeks observational tools for rapidly determining the characteristics of near surface sediments in strategically important areas in order to apply the predictive algorithms properly. The purpose of the proposed study is to develop an *in situ* fiber-optic microprobe that utilizes visible light radiation to determine sediment characteristics such as bulk density, mean grain size, porosity, and microfabric that is deployable over a wide range of seafloors from mud to sand (carbonate and siliciclastic). This tool, when deployed by the operational Navy, would allow for rapid mapping of sediment type and geotechnical properties by remote means, particularly when used in concert with existing probe technology (e.g., sediment resistivity probes). Potential deployment platforms include autonomous ROV's, wire-deployed profilers, and bottom tripods.

OBJECTIVES

The principle objective of the present research is to develop and test a probe that could be designed for fully *in situ* ocean conditions (including electronics) and that could be mounted with other devices (sediment resistivity probes, suspended sediment concentration sensors, etc.) on bottom deployed tripods or operated from the surface attached to water column/sediment profilers. The fiber-optic sensor would be deployable in a wide variety of sediment types to determine fully the nature of the sensor response to allow its calibration for use as a sediment density probe in water column/seabed and a grain character probe (grain size and orientation).

APPROACH

Year 1 of this project was a laboratory phase. In this phase, a probe will be designed for commercial fabrication. This probe will be tested in a wide variety of sediments in the laboratory to determine its response/calibration characteristics. Year 2 will be a field phase of testing of the finished probe package. This will include the hardware and software necessary to deploy on a field tripod mounted in a shallow water system. Lake Pontchartrain, Louisiana is the tentative field deployment site. This area is 2-4 m deep and the test site will be a platform of other sensors operated by the Louisiana Universities Marine Consortium (LUMCON). Existing work from the site suggests it is a site of fluid mud formation associated with passage of winter cold fronts—a topic of interest to the Navy and the scientific community as a primary mechanism for transporting and burying shelf sediment adjacent to large river discharges and in estuaries. This will provide useful scientific data as well as a thorough test of probe capabilities. In this deployment, electronics and power supply will be fully submersible.

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At the end of Year 2, enough information should be available to deploy an automated planar probe that would be useful to the operational Navy as well as other oceanographic investigators. This system would include an underwater electronics package that would hold the light source and receiving spectrometer for the microprobe. Datalogging hardware and software will have to be designed to control movement of the probe, data collection, and data storage. Finally, the probe will be integrated with deployment packages used by other investigators examining sediment characteristics such as bulk properties. It is presently proposed to utilize this package for the upcoming ONR-supported field experiments for the ONR Mine Burial Initiative.

WORK COMPLETED

Since the beginning of the project in the Spring of 2001, several major tasks have been completed:

Prior to ONR FY01 Annual Report

1. *Probe Design and Fabrication* – After laboratory testing a number of configurations for the planar, fiber-optic probe, a final design was decided upon that uses dual, 200 micron UV/VIS fibers in a 10 cm, stainless steel probe hull. Ocean Optic, Inc. of Dunedin, Florida was contracted to fabricate a prototype of this design. Corporate involvement was deemed necessary to arrive at a reproducible design, after much experience with fabrication in my laboratory. This prototype has been tested extensively and is successful (see below)
2. *Flume Experiments* -- As all tests to date on the probe had been in core material in the laboratory, it was determined that the next step would be to test probe response in a laboratory flume experiment using intact core material and simulating real world marine conditions. To this end, in July 2001 a set of successful experiments were conducted on the LUMCON flume at Cocodrie, Louisiana using the prototype Ocean Optics probe.
3. *Design of Autonomous Array* – As part of the ONR DURIP proposal process in August 2001, a prototype submersible deployment system (tripod) for the microprobes was designed. A proposal was submitted with R. Wheatcroft (OSU), who is interested in similar tripod design, for inserting electrical resistivity probes. If funded, this venue and design would allow the results of the present funded project to transition rapidly to a fully submersible system.

In FY02 (For Present Annual Report)

4. *Extensive Laboratory Experiments* -- to determine the sediment controls on probe response and the potential of calibrating probes to determine in situ sediment porosity, suspended sediment concentration, grain size, and organic content.
5. *Construction of Autonomous Array* – Working with Ocean Optics, Inc. and Rex Johnson of the Oceanography Shop at University of Washington, the prototype submersible deployment system for the microprobes is under construction and should be complete by November 2002. The design includes four individual probes wired to a single broadband LED light source and quadfurcated to separate spectrometers. A fifth spectrometer will be included wired to a fiber-optic oxygen (FOXY) sensor (1 mm diameter probe). The spectrometers will be encased in a pressure housing and controlled by an Onset Computer Tattletale Model 8v2 datalogger equipped with 1 GB of flash memory. One microprobe and the FOXY sensor will be deployed on a two-axis insertion arm constructed by

University of Washington to be inserted up to 25 cm depth across the sediment-water interface. The other three fiber-optic sensor will be deployed at fixed depths in the benthic boundary layer to measure sediment concentration. The prototype instrument has been funded through the ONR DURIP program along with other instrumentation for a bottom tripod designed to provide an integrated look at fluid, flow, suspended sediment, and upper seabed properties in a variety of sedimentary settings.

RESULTS

In the FY01 Annual Report, results were presented that demonstrated the success of a set of experiments that prove the value of the probes as a sediment density sensor on micro-depth scales over a wide range of sediment concentrations from water column to seabed, and 3) the value in real world studies of tracking high-frequency effects to the bed over length scales from microns to centimeters. In Figure 1 and 2 from laboratory experiments in FY02, it is apparent that the probes also have value for examining grain size and stratigraphy in the upper seabed. Grain size response of the probes is primarily in sensing mud content in sandy sediments—the probes are relatively insensitive to grain size changes in the silt and clay size classes and when mud vs. sand when mud content exceeds 40% (Figure 1). The former makes the sensors less sensitive to grain size change when being calibrated as a suspended sediment sensor. In sediments primarily composed of mud, laboratory experiments with flocculated vs. laminated muds (not shown) have shown there is a significant variation in probe response to platy mineral orientation, giving promise of the probes for examining microfabric of the upper seabed. Finally, use of 670nm chlorophyll-a pigment absorption (not shown) indicates there is promise of utilizing the probes for determining gross organic content of sediments.

In the remaining months of the grant (ends 12/31/03), I will concentrate on construction of the submersible system, deployment in Lake Pontchartrain in November/December 2002 during a 2-3 day cold front passage sequence, and analysis of the initial results and performance of the system. Under a ONR Marine Geoscience proposal now under consideration, the probes and the bottom tripod would be utilized in March 2003 for the Mine Burial Initiative on the West Florida margin to examine the formation of sediment-stabilizing biofilms on sandy substrates.

IMPACT/APPLICATIONS

The development of a robust probe that can be calibrated as a sediment sensor holds great promise for its use in remote deployments by divers or ROV/AUV's. It's low cost (\$300 for the prototypes) also suggest the possible use of these probes in a single-wavelength (no spectrometer) configuration on expendable, ship-deployed sensor packages for relaying information about bottom type in areas of strategic importance to the Navy. In terms of scientific value, the flume experiment demonstrates its value for examining small-scale, near bed sedimentary processes in turbid environments.

TRANSITIONS

The early results of this development have been noted by a number of other investigators. To date, investigators from LUMCON (Finelli and Powell), VIMS (Frederichs), and SKIO (Alexander) have expressed an interest in utilizing these probe in their own work. Working with Ocean Optics using the design developed by this proposal, Finelli has reached the stage of acquiring probes and testing them in the laboratory.

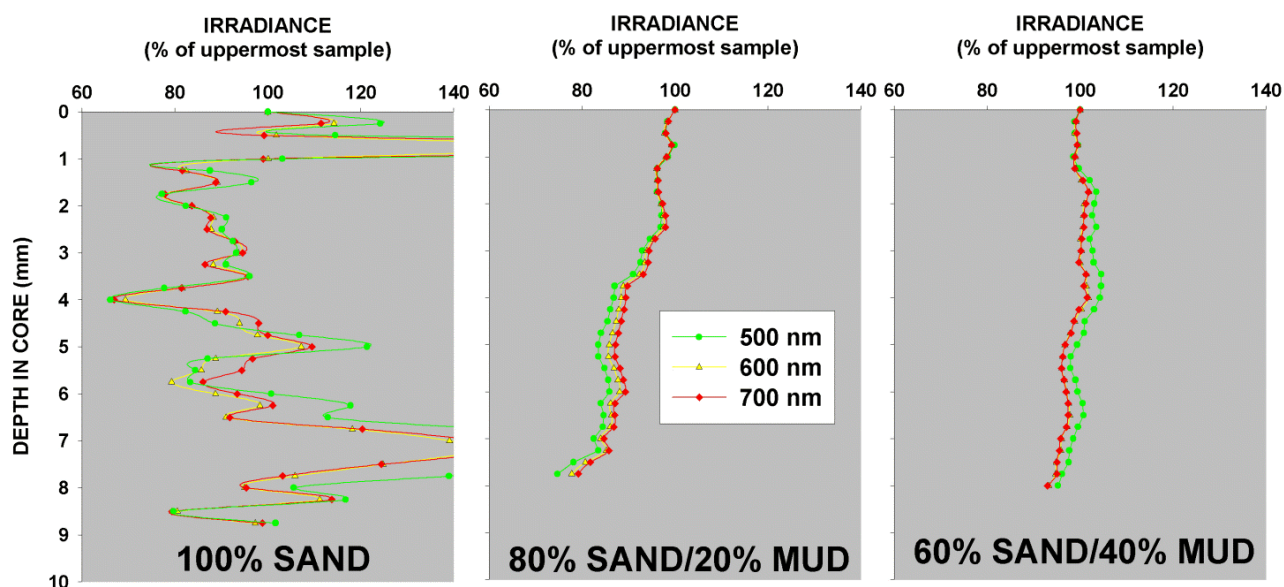


Figure 1. Self-illuminated fiber-optic microprobe sediment profile of artificial sediment columns plotted as %irradiance relative to the first (uppermost) sample at 600 and 700 nm. The sand is a sieved 2-3 ϕ natural beach sand from Galveston Island, Texas and the mud is a natural silty clay (w/ 2% organic matter) from a south Louisiana tidal flat prepared by sieving out the sand fraction and drying the mud before determining proportions in the final sample. Samples were rehydrated to 70% initial porosity and added sequentially to a sample container. Analysis took place one day after sample preparation. All profiles were begun at 5 mm below the sediment surface to remove surface effects. This profile demonstrates the potential of the microprobes for remote measurements of seafloor grain size properties in sandy sediments. At 100% sand content there are large sample-to-sample variations in relative irradiance. This is likely a function of the relative size of particles to the probe size (450 microns) leading to a heterogenous optical field. Note also the differences between irradiance at 500, 600 and 700 nm. This is also likely a function of the individual sand grains affecting refraction and scattering around the probe tip. At only 20% mud content, there is a sharp decrease in both sample-to-sample variations and wavelength differences that is only marginally more pronounced at 40% mud. In both the 20 and 40% mud profiles there is an overall downcore decrease in relative irradiance due to decreasing (compaction-induced) porosity.

RELATED PROJECTS

The ONR DURIP funded in Summer 2002 is being utilized to move the experiments from the laboratory into a fully deployable field system more rapidly than was initially proposed for this study.

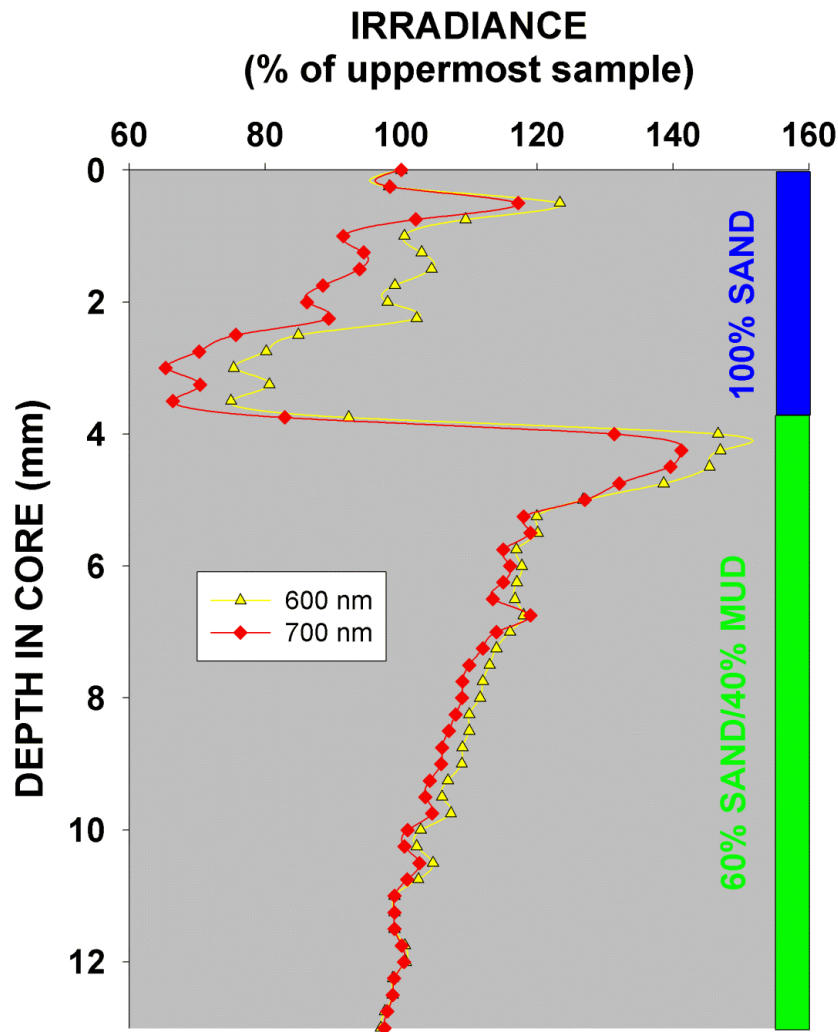


Figure 2. Self-illuminated fiber-optic microprobe sediment profile of an artificial two-layer sediment column (upper layer 100% sand, lower 60% sand and 40% mud) plotted as %irradiance relative to the first (uppermost) sample at 600 and 700 nm. The sand is a sieved 2-3 ϕ natural beach sand from Galveston Island, Texas and the mud is a natural silty clay (w/ 2% organic matter) from a south Louisiana tidal flat prepared by sieving out the sand fraction and drying the mud before determining proportions in the final sample. Samples were rehydrated to 70% initial porosity and added sequentially to a sample container. Analysis took place one day after sample preparation. This profile demonstrates the potential of the microprobes for remote measurements of seafloor grain size properties, porosities, and physical sedimentary structures. The upper sand layer shows large sample-to-sample variability in relative irradiance and in the wavelength variations characteristic of sands (see Figure 1), and a downcore decrease in relative irradiance due to decreasing (compaction-induced) porosity. The sharp irradiance change at the basal contact is produced by the large difference in porosity and scattering characteristics of sand vs. muddy sand. The muddy lower layer has limited sample-to-sample variability in relative irradiance and in the wavelength variations, and a downcore decrease in relative irradiance due to decreasing (compaction-induced) porosity. Given that calibration curves could be developed by using sediments collected from a site, this data suggests real seafloor fiber-optic microprobe profiles could be utilized to show downcore trends in porosity and/or grain size.

PUBLICATIONS

None at present. It is anticipated that after *in-situ* field data is acquired in the Lake Pontchartrain experiment in November-December 2002, a publication will be prepared demonstrating the values of these probe systems to the general oceanographic community.